

# Novice designers' use of prototypes in engineering design

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*Prototypes are essential tools in product design processes, but are often underutilized by novice designers. To help novice designers use prototypes more effectively, we must first determine how they currently use prototypes. In this paper, we describe how novice designers conceptualized prototypes and reported using them throughout a design project, and we compare reported prototyping use to prototyping best practices. We found that some of the reported prototyping practices by novice designers, such as using inexpensive prototypes early and using prototypes to define user requirements, occurred infrequently and lacked intentionality. Participants' initial descriptions of prototypes were less sophisticated than how they later described using them, and only upon prompted reflection did participants recognize more specific benefits of using prototypes.*

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Prototyping is a combination of methods that allows physical or visual form to be given to an idea (Kelley & Littman, 2006; Schrage, 2013) and plays an essential role in the product development process, enabling designers to specify design problems, meet user needs and engineering requirements, and verify design solutions (De Beer, Campbell, Truscott, Barnard, & Booyesen, 2009; Moe, Jensen, & Wood, 2004; Viswanathan & Linsey, 2009; Yang & Epstein, 2005). Designers tend to think of prototypes as three-dimensional models, but nonphysical models, including 2D sketches and 3D CAD models, as well as existing products or artifacts, can also serve as prototypes (Hamon & Green, 2014; Ullman, Wood, & Craig, 1990; Wang, 2003).

Prototypes can help minimize design errors that may otherwise occur both early and late in the process. Often, prototypes can be created quickly and inexpensively and serve as effective models to help designers identify design issues and learn from failures (Kelley & Littman, 2006; Kordon & Luqi, 2002). Therefore, many advocates suggest that prototypes should be created early and used iteratively throughout the product design process (Clark &

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Fujimoto, 1991; Yock et al., 2015). Tom Kelley, chief executive officer of the global design firm IDEO, called prototyping ‘the shorthand of innovation’ and encourages rapid and frequent prototyping (Kelley, 2007). Schrage argued that prototypes should be regarded as disposable artifacts to discover opportunities and quickly eliminate less promising solutions (Schrage, 2013). This proposed ‘quick and dirty’ prototyping approach supports a greater number of iterations and enables designers to select the best solution to a design challenge without large amounts of ‘sunk cost,’ i.e. time and money, invested (Houde & Hill, 1997).

Expert designers leverage prior experiences to inform their design decision making processes and consider a broad spectrum of solutions before synthesizing information and selecting a concept for refinement (Cross, 2004; Ho, 2001; Lawson, 1994). Expert designers also use multiple and varied prototypes during all phases of product design (Crismond & Adams, 2012; Hilton, Linsey, & Goodman, 2015) to reduce complexity and achieve ‘small wins’ at the component level (Gerber, 2009). Working with prototypes at the component level and the ability to switch between component- and system-level thinking are crucial to successful design as practiced by design experts (Hilton et al., 2015; Viswanathan, Atilola, Goodman, & Linsey, 2014). A number of factors related to prototyping influence the design outcome, including the development of a structured approach for when and how to use prototypes, time spent on prototyping, and the complexity of the prototypes developed (Atman et al., 2007; Camburn, Dunlap, Kuhr, et al. 2013, 2015; Häggman, Tsai, Elsen, Honda, & Yang, 2015; Yang & Epstein, 2005). Design experts leverage their accumulated knowledge and experience and select the most appropriate approaches to prototyping to answer specific design questions (Houde & Hill, 1997) and rely heavily on prototypes to quickly test an idea or generate new ones. By doing so, they improve a concept and advance the design through the individual project phases (De Beer et al., 2009; Dow et al., 2010; Knapp, Zeratsky, & Kowitz, 2016).

The ability to demonstrate ideas through prototypes, rather than describing concepts verbally only, is critical early in a design project when developing a deep understanding of stakeholder needs (Skaggs, 2010). Stakeholders ultimately determine if a solution successfully addresses a design problem and therefore, stakeholders should be an integral part of the design process (Kelley, 2007; Schrage, 2013; Yock et al., 2015). However, eliciting and synthesizing sometimes conflicting stakeholder information can be difficult for designers (Mohedas, Daly, & Sienko, 2014c; Scott, 2008) and can lead to superficial design changes that do not address underlying deficiencies (Sugar, 2001). Prototypes are often the visual and tangible tools for communicating ideas, especially during the front-end phases of design, including problem definition and ideation (Goldschmidt, 2007; Koen et al., 2002, pp. 5–35; Mohedas, Daly, & Sienko, 2015; Mohedas, Sabet Sarvestani, Daly, & Sienko,

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